Computerized Data Acquisition/ Reduction for the Ohio State University Rate of Heat Release Calorimeter

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DOT/FAA/CT-TN83/01

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16. Abstract		

Technical note DOT/FAA/CT-TN83-01 provides acquisition and plotting software documentation to the Ohio State Rate of Heat Release Calorimeter with chemical analysis system. Hewlett Packard 9825 Computer programs provide for real-time data collection, instrument calibration, data storage, retrieval, and output for release of heat, smoke, carbon monoxide, carbon dioxide, oxygen, hydrogen cyanide, nitrogen oxides, and hydrocarbons. Graphical representation for both release rates or total output versus time is possible. Computer language is HPL.

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Approximate Conve		When You Know				feet	yards	miles			square inches	square yards	square miles	acres	M		ounces	pounds short tons	(2000 lb)			teaspoons	tablespoons	fluid ounces	cnps	pints	quarts	cubic feet	cubic yards	TEMP		Fahrenheit temperature	1 in = 2.54 lexacity). For other exact conversions and more detailed tables, see NBS	ts and Measures, Price \$2.25, 3
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11 in = 2,54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 236, Units of Weights and Measures, Price \$2,25, SD Catalog No. C13,10,286.

EXECUTIVE SUMMARY

Technical note DOT/FAA/CT-TN83-01 provides acquisition and plotting software documentation to the Ohio State Rate of Heat Release Calorimeter with chemical analysis system. Hewlett Packard 9825 Computer programs provide for real-time data collection, instrument calibration, data storage, retrieval, and output for release of heat, smoke, carbon monoxide, carbon dioxide, oxygen, hydrogen cyanide, nitrogen oxides, and hydrocarbons. Graphical representation for both release rates or total output versus time is possible. Computer language is HPL.

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by Robert Filipczak

Background

Heat release by combustible furnishings may be the single most important factor in the propagation of interior fires and concurrent threat to human survivability. This is also true of aircraft fires due to the incombustibility of the airframe itself. The Ohio State University Heat Release Calorimeter developed by Edwin Smith is currently being considered as an ASTM test method to evaluate the heat and smoke release rates of a material exposed to a fire. In addition, the FAA has instrumented the OSU with continuous chemical analysis instruments for carbon monoxide, carbon dioxide, oxygen, hydrocarbons, nitrogen oxides and hydrogen cyanide to more completely document the combustion phenomena and toxic gas production.

A Hewlett Packard 9825T, equiped with a 3495 scanner and 3490 Digital Voltmeter, is programmed to acquire, reduce and store the large amount of data generated. Data output is accomplished via 9862A XY Digital Plotter which produces report quality graphs of heat, smoke and chemical release rates or their integrals (total heat, smoke and chemical production verus time). This report documents the software developed to accomplish this task, defining the data structures and algorithms used.

Discussion

General - The McDonnel Douglass Corporation, under contract number DOT-FA77WA -4091 for the FAA, instrumented in the Ohio State Role of Heat Release Calorimeter the first attempt at a combined hazard index test methodology. The FAA has now acquired its own system as a research tool to evaluate aircraft materials on a routine basis. Ultimately, data will be collected for correlation of OSU performance versus full-scale results via the Dayton Aircraft Fire (DACFIR) mathematical cabin fire modes.

Several departures of the McDonnell Douglas apparatus and software have been effected. The chief apparatus difference is that the FAA runs the OSU Calorimeter in accordance with the ASTM E-5 committee recommendations. That is 6 x 6-inch square environmental conditioned sample with 84 cubic ft/min air flow. All procedures are standard, except that a sample of 20 liters per minute is drawn from the inner pyramidal-cone. Test with and without sampling have shown identical response factors during methane calibration.

Completely new software has been written for data acquisition. The FAA acquisition program stores data gathered in matrix form as opposed to a long continuous string. Eight channels (CO, CO₂, O₂, CH_x, NO_x, HCN, Smoke, DTP) correspond to the rows at the matrix, and 301 columns correspond to the sample time (0 to 10 minutes at 2-second intervals). Each value stored for the gases is in parts per million except oxygen which is in percent, while smoke and thermopile values are voltages.

Gas values are converted to grams per minute per square meter, heat to kilowatts, and smoke to specific optical density in the plotting software after the acquired data is stored on tape. This is convenient, since units of measure can be easily changed with slight modifications. In addition to the acquisition program, two separate plotting programs have been written, one plots rate data and the other plots the total heat, smoke, and gas yields (integral of the rate function).

Software discriptor

A. CHI Data Acquisition Program (Figure 1)

```
Statement 0-6 Dimensions and assigns variables
Array A(5)-Run time
      A(1)-month A(2)-Day A(3)-Hour A(4)-Minute A(5)-Second
Array B(6) run discriptor B$ -Material Name
                                        B(2) Run number
      B(1)-Material number
                                        B(4)-Data tape #
      B(3)-Heat flux
                                        B(6)-file number
      B(5)-tape track
                                        CS-Channel name
Array C(11)-Calibration Information
                                        C(1)-CO full-scale concentration
      CS(1)-Carbon Monoxide
                                        C(2)-CO_{I} full-scale concentration
      C$(2)-Carbon Dioxide
                                        C(3) O_2^- calibration concentration
      C$(3)-Oxygen
                                         C(4) \overrightarrow{CH}_{x} full-scale concentration
      C$(4)-Hydrocarbons
                                               \mathrm{NO}_{\mathrm{X}}^{-} full-scale concentration
      C$(5)-Nitric Oxide
                                         C(5)
                                               HON full-scale concentration
      C$(6)-Hydrogen Cyanide
                                         C(6)
                                               0% Transmittance Voltage
                                         C(8)
      C$(7)-Smoke
                                        C(9) 100% Transmittance Voltage
                                         C(10)-Thermopile calibration factor
      C(8)-Differential Thermopile
                                         C(11)-Thermopile voltage at zero
                                                heat release
                                         C(7) Dummy variable for plotter
                                               routines
```

R(8, 301)- Acquired run data where R(I,J) I equals channel number and 2J equals run time slice in seconds

Whenever a calibration gas tank is changed, statement 6 must correspondingly be changed to reflect the proper concentrations.

Statement 7-12 format the internal printer output. A short printout documents, the key run data (array B(6)), time of run (array A(5)), and calibration values.

```
format 1 - prints out time of run
format 2 - selects proper range and function for the digital voltmeter
format 3 - select the proper scanner channel
format 4 - prints out gas name and concentration
format 5 - prints out smoke meter voltage values
format 6,7 - prints out thermopile values
```

Statements 13-23 interact with operator for input of data. Statement 14 tells the clock to take a reading (writes from the computer to clock). Statement 15 takes clock data and enters in into computer memory. The remaining statements enter and printout run data to the program.

Statements 24-44 autocalibration for the system. Until the analysers are calibrated within 1 percent full-scale data cannot be collected. The scanner (address 709, format 3) channel is selected (statement 29), and the voltmeter (address 722, format 2) is set to the appropriate range and function (statement 30). The analyser voltage output is read (statement 31) and a series of if statements is used to set the proper conditions depending on the analyser. Channel 3, the oxygen analyser, has a 1-volt output when the concentration is 25 percent so that the faction of volt times 25 equals concentration when properly calibrated. system will keep reading until the span potentiometer is adjusted, kicking out of the loop when set. Channel 6, the HCN analyser, has an output one tenthousandth of the concentration. For example, 110 ppm calibration gas will have a voltage output of 11 mv when calibrated properly. When within 1 percent of this value statement 35 allows the program to continue. All other analysers have a 1-volt output when properly calibrated, so array value C(I), where I is the channel number, times the voltage equals C(I) (statements 37, 38). Should a value be accepted while adjustment of a span potentiometer is occuring, statements 39 through 43 advance to the next channel sequently until all analysers are calibrated.

Statement 45-55 Zero analysers for the system. Statements are similar to the autocalibration routines. Air is sampled and the zeroing potentiometer is adjusted. Channels 3 and 6 are skipped because the analysers are absolute zero (no adjusting potentiometer).

Statements 56-78 calibrates the smokemeter. Because the signal is noisy, ten samples are taken and averaged. Voltage values are stored in C(8) and C(9) for zero percent transmittance and 100 percent transmittance, respectively. If values are not acceptable, statements 66 and 77 allow adjustment of the smokemeter and rerunning the calibrations.

Statement 79-88 collects the differential thermopile baseline millivolt signal. Again, an averaged signal is taken because of noise.

Satement 89-97 printout the calibration data for all channels on the calculator's internal printer.

Statements 98--102 baseline oxygen measurement is taken. C(3), the oxygen calibration value is reassigned after the printout to the baseline oxygen concentration for oxygen depletion heat release measurements. If oxygen concentration is 20.9 percent this routine would be unnecessary since atmospheric concentration is constant. However, in the Ohio State University calorimeter, piloted burns consume some oxygen via the methane pilot. Due to the sensitivity of 0_2 depletion measurement to very small oxygen concentration changes, this is good practice, even in unpiloted burns.

Statement 105 to 118 are the data Acquisition Routine. Statements 106, 107, and 117 address the clock to take a measurement and compare it to the last time measurement taken. The variable T is the number of seconds since the day began. When T is two seconds greater than the last measurement, the program enters the acquisition loop for the eight channels. As before, there is special treatment for channels 3, 6 and 8. All others measure the voltage and multiply it by the calibration concentration. Channel 7 stores voltage values as does 8, but C(7) the dummy variable (1) is used where C(8) is not unity and is important to the

plot routine, thus requiring the extra if statement 114. After all eight channels are sampled, the program returns to the clock read loop until two seconds pass and the next set of data is acquired.

Statements 119 to 121 All data collected is stored on tape and the program is finished.

B. CHI Data Plotting Programs (Figures 2 and 3)

Once data are stored on tape via the acquisition program, subsequent analysis and reduction is accomplished through two different programs. Of primary interest are answers to the questions; 1) At what rate are heat and toxic gases being given off? 2) What is the cumulative heat, smoke, and gas concentrations? Rate data provides a basis to predict the propagation of the fire while total release gives an idea of the probability of survival within a time framework.

The two programs are identical through statements 0 to 56. At this point the integrals program introduce a new variable which simply adds the next rate increment to the previous one. Since a two-second interval is the data sampling rate, each sample is divided by 30, for the increment of production per minute. Likewise the Y-axis labels are different for the two programs.

Statements 0-14 allocates memory (statement 4) and loads the data (statements 6 and 7) from tape with a printout identifying the run.

Statement 15 allocates and assigns values to the matrix to correct the part per mullion values for molecular weight when converting concentrations to grams.

Gas Release Rate = concentration x flow rate x molar volume x molecular weight.

GRR = _____

(6 x 6)
$$in^2 x \frac{(2.54)^2 cm^2}{in^2} x \frac{m^2}{(100)^2 cm^2}$$

GRR = (ppm) (molecular W+) x .001063 (9) min m²

S[I] = molecular weight of specis I
S = .001063

For convenience of programming, smoke and thermopile voltages are multiplied by one leaving them unchanged. If sample size or OSU flow rates change, the variable S must also be changed.

Statements 17-21 correct the thermopile voltage with a blank run at the appropriate heat flux. When injecting a material into the OSU calorimeter, the cold sample holder and heat escaping into the plenum chamber causes the thermopile voltage to dip early in the test. Also at the end of the test the sample holder tends to reflect heat increasing the thermopile voltage composed to zero. To correct for these phenomenage, an empty sample holder is injected in the normal fashion and a computer file stored on tape for each heat flux. This file is added to thermopile voltage file later in the plot routine.

Statements 22-25 select the channel to be plotted, displaying the information to the operator.

Statements 27-37 set the full scale values for the plots where I is the channel. If the scale is too large or small for the data plotted, changing the appropriate assignment for A will change the scale (statement 36) for that channel. Statement 37 draws the axis and tic marks.

Statements 38-47 label the graph according to material name and number, burn number and heat flux.

Statements 48-58 plot the data for channels 1, 2, 4, 5, and 6.

Statement 57 multiplies the part per million value by the appropriate molecular weight conversion factor and plots the release rate for that gas. The integral plotting program divides the rate by thirty and adds it to the previous value, the variable T, and plots it (statement 59).

Channels 3 and 8 are heat release rates and are treated in a different manner than gas release rates. Oxygen depletion heat release rate is calculated as follows. l (statement 49)

```
Heat Release Rate per area = \frac{Q}{A}

Q = H \times V [X_O - X_t]

Where H = molar enthalpy of oxygen = .167 x 10 KV/m<sup>3</sup>
V = OSU \text{ inner pyramidal flow} = .01 \text{ m}^3/\text{sec}
X_O = \text{molar fraction } 0_2 \text{ at T} = 0
X_t = \text{molar fraction } 0_2 \text{ at time t}
A = .02323

HRR = \frac{1.67 \times 10^4 (.01) (X_O - X_t)}{.02323}
= 1.4378 (X_O \times X_t)
```

Heat release for the thermopile is calculated measuring the difference between the initial thermopile voltage and the voltage while the material burns multiplied by a calibration factor. The thermopile voltage is corrected for backgroud (statement 50). The calibration factor is determined by burning a known flow of methane (heat and measuring the thermopile voltage change.)

Statements 51-57 calculate the smoke release rate. Since the smokemeter is not linear with respect to percent transmittance, linear numerical techniques² are used to directly calculate %T from smokemeter voltage.

(Standard Metric Optical Kinetic Emmission) if the units desired are Ds, the S.M.O. K.E. should be divided by 60 since units are sec.-l rather than min-l.

Statements 59-80 label the axes of the graphs. First the X axis is labeled (statements 60-66), then the Y axis with conditional is statements depending on channel. Statement 79 sends the program back to statement 22 for the next plot. The program continues until manually stopped.

References

- 1. D. Sensenig "An Oxygen Consumption Technique for Determining the Contribution of Interior Wall Finishes to Room Fires" NBS note 1128
- 2. W. Cheney and D. Kincaid, <u>Numerical Mathematics and Computing</u>. Brooks Dole Publishing Co., 1980

```
42: if I=6;0+
                      20: enp "Heat
0: dsm "CHI Dota
                                             C[6]*100+D[6];
                       Flux W/cmt2",
 Aquisition"
                                             eto 44
                       8[3]
1: wait 5000
                                             43: C*C[I]+D[I]
                      21: enp "Tape
2: dim A[5].B[8]
                                             44: next I
                       #",B[4]
                                             45: dsp "Zero
 ,B$[20],C[11];
                      22: enp "Track
                       #",B[5]
 C$[8,20],R[8,
                                             -Analysers";wait
 301]
                                              5000
                       23: enp "Tape
9: dim D[6]:D$[1
                                             46: dsp "Ready,
                       file #".8[6]
                                             press continue"
                       24: rem 7
4: "00"+0$[1];
                                             istp
                       25: clr 722
 "CO2"+C$[2];
                                             47: for I=1 to 5
                       26: for I=1 to 6
 "02"+C#[3]; "CHx
                                             48: wrt 709.3,I
                       27: dsp "Calibra
                                             49: wrt 722.2
 " + C # [4]; " MOx" + C
                       te for ":0$[];
 $[5];"HCN" >C$[6
                                             50: red 722,0
                       wait 5000
                                             51: dsp ($[I])
                       28: dsp "Ready
5: "8.M.O.K.E."+
                                             "=",D*C[]]
                       press continue
 C$[7]; "Thermopi
                                             52: wait 2000
                       istp
 le"→C$[8]
                                             53: if I=3;jmp 2
                       29: wrt 709.3,I
6: 4900+C[1];
                                             54: if obs(D)).0
                       30: wrt 722.2
 25700+C[2];16.7
                                             05; sto 49
                      31: red 722,0
 +C[3];20500+C[4
                                             55: next I
                       32: if I=3;dsp
 ];501+0[5];105+
                                             56: dsp "Install
                        C$[];"(";C[];
 [6]
                                              smoke, press
                        ")",C*25;wait
                                              continue";1+0[7
7: fmt 1, f2.0;
                        2000; if abs(C*
 c1,f2.0,2x,f2.0
                                             ];100+Z;stp
                        25)-0[]]).1;
 .c1,fz2.0,2/
                                             57: wrt 709.3,7
                        jmp -2
8: fmt 2,"R5F080
                                             58: 0+F
                       33: if I=3;9to
 TimaE",z
                                             59: for I=1 to
                       39
9: fmt 3,fz2.0
                                             10
                       34: if I=6;dsp
10: fmt 4:c4:x:
                                             60: wrt 722.2
                        C$[]],"(",C[]],
 c1,f7.1
                                             61: red 722,E
                        ")",10000*C;
11: fmt 5,f3.0,
                                             62: wait 1000
                       wait 2000
 c2,x,f6.4<c3
                                             63: E+F+F
                       35: if I=6; if
12: fmt 6, f5. i,
                                             64: next I
                        abs(C[I]-C*1000
 3 \times , c7
                                             65: F*.1+F;F+C[8
                        0)).01*C[];
13: fmt 7,f6.3,
                                              ]
                        jmp -5
 2x:c7
                                             66: dsp "0% Tran
                       36: if I=6; etc
14: wrt 9, "R"
                                             s -";F;"VDC";
                       39
15: red 9,A[1],
                                              wait 2000;ent
                       37: dsp ($[I],
 A[2],A[3],A[4],
                                              "Acceptable Y/
                        "\ (\ "\ ,\ C\ [\ I\ ]\ ,\ "\ )\ "\ ,\ C\ \div
 A[5]
                                              n":O$
                        C[I]; wait 2000
                                             67: if D$="n";
 16: wrt 16.1,
                       38: if abs(C-
 A[1], "/", A[2],
                                             ato 59
                       1)).01;9to 30
 " * * * A [3] * " * " *
                                             68: dsp "Remove
                       39: ent "Cal
 A[4]
                                              smoke, press
                        acceptable (y/
 17: enp "Materia
                                              continue";stp
                        n)",D$[1]
 1 "= 日本
                                             69: 0+H
                       40: if D$[1]="n"
 18: enp "Materia
                                              70: for I=1 to
                       isto 30
 1 #",E[1]
                                              10
                       41: if I=3;C+
 19: enp "Burn
                                              71: wrt 722.2
                        25+D[3] isto 44
 #",8[2]
                                              72: red 722,G
                                              73: wait 1000
```

FIGURE 1. CHI ACQUISITION PROGRAM (Sheet 1 of 2)

```
101: (0 ± . 1) 25 → C[
74: G+H+H
                                  31;prt "Oxygen
75: next I
                                  baseline";wrt
76: H/10+H;H+C[9
                                  16.7,0%25%" 4"
٦
                                  102: stp
77: dsp "100%
                                 103: dsp "System
 Trans -" , H , " VDC
                                   readyipress
 "; wait 2000;
                                  continue"
 ent "Acceptable
                                  104: stp
 y∕n",D$
                                  105: for I=1 to
78: if D$="n";
                                  301
9to 69
                                  186: wrt "9";
79: dsp "Thermop
                                  red 9 6 6 6 7 8 8 12 1
 ile cal";23.823
                                  ,6 [4],A[5]
 +C[10];wait
                                  107: if T>3600*
 2000
                                  A[3]+60*A[4]+
80: wrt 709.3,8
                                  A[5] fimp -1
81: for I=1 to
                                  108: for J=1 to
 10
                                  S
82: wrt 722.2
                                  109: wrt 709.3,J
83: red 722,M
                                  110: wrt 722.2
84: H+M+H
                                  111: red 722:V
85: wait 1000
                                  112: if J=3;V*
86: next I
                                  25+R[3,]]; sto
87: N*.1+H;N+C[1
                                   116
1]
                                  113: if J=6; V*
88: dsp "Thermop
                                  10000+R[6,I];
 ile -",N*1000,
                                  ato 116
 "mv";wait 2000
                                  114: if J=8; V + R[
89: for I=1 to 6
                                  8:I];sto 116
90: wrt 16.4,
                                  115: V*C[J]→R[J;
C$[1],"=",D[I]
                                   IJ
91: next I
                                  116: next J
92: prt "Smoke
                                  117: A[3]*3600+
 Ca.1 "
                                  A[4] *60+A[5]+
93: wrt 16.5,8,
                                   \mathbb{Z} + \mathbb{T}
 "%T",F,"VDC"
                                  118: next I
94: wrt 16.5,Z,
                                  119: trk B15]
 "%T",H,"VDC"
                                  120: rot 8[6]:
95: prt "Thermop
                                  A[+],B[+],B$,
 ile"
                                  96: wrt 16.7,N*
                                  1211 end
 1000,"mu@zero"
                                  *21599
97: wrt 16.7,L,
 "kWzmv"
98: dsp "Install
  data tape, pres
s cont."
99: wrt 709.3,3
100: for I=1 to
 10; wrt 722.2;
 red 722, P; Q+
 P+0inext I
```

FIGURE 1. CHI ACQUISITION PROGRAM (Sheet 2 of 2)

```
54: 249.326(X-
                       24: wait 5000
                                               .5)(X-.425)+Z[2
8: fmt 1,f2.8:"/
                       25: dsp "Set up
                                               ]
 " + f z 2 . 0
                        plotter, press
                                               55: -102.666(X-
1: fxd 0
                        cont"
                                               .5) + Z[1]
2: dsp "CHI Plot
                       26: stp
                                               56: if I=7,771.1
 ter control-
                       27: if I=1;250+A
                                                *log(100/(Z[1]+
 rates"
                       28: if I=2;2000+
                                                Z[2]+Z[3]+Z[4])
3: wait 5000
                        Ĥ
                                                ) → R [7, J]
4: din A[5],8[6]
                       29: if I=3;250→A
                                               57: plt (J-1)*2,
 ,B$[29],C[11].
                       30: if I=4;200+A
                                               R[I,J]*S[I]
 C$[8,20],R[8,
                       31: if I=5;20+A
                                               58: next J
 3011
                       32: if I=6;10+A
                                               59: csiz 1.5,2
5: ent "Input
                       33: if I=7;250→A
                                               60: for K=1 to
 tape track and
                       34: if I=8;1000+
                                               10
 file #".A.B
                        Α
                                               61: plt 60*K-20,
6: trk A
                        35: fxd 0
                                                -.05A,1
7: ldf B,A[*],
                        36: scl -50,620,
                                               62: lbl K*60
 B[*],B$,C[*],
                        -.1A,1.05A
                                               63: next K
 C$ • R [*]
                        37: axe 0,0,30,
                                               64: pen; plt 240,
8: wrt 16.1,A[1]
                        .18
                                               -.1A,-2
 , A [2]
                        38: plt 200,.97A
                                               65: csiz 2,2
66: lbl "Time
9: pri B$
                        , 1
10: spc
                        39: csiz 3,2
                                               (sec)"
11: prt "Materia
                        40: 161 B$,B[1]
                                               67: plt -30,.3A,
 l #",B[1]
                        41: cplt -15,-1
                                               - 1
12: prt "Burn":
                        42: csiz 2,2
                                               68: csiz 2,2,8/
                        43: 161 "Burn",
B[2],", "
 8[2]
                                                11,90
13: fxd 1
                                               69: if I=3:1bl
14: prt "W/cm12"
                        44: fxd 1
                                                C$[]]," Depleti
 , B [3]
                        45: 1bl B[3],"
                                                on HRR-kW/sa
 15: dim S[8],
                        W/cm†2"
                                               meter"; sto 73
 Z[4];.001063+S;
                        46: fxd 0
                                               70: if I=7;1bl
 S*28+S[1];S*
                        47: plt 0,0,-2
                                                "S.M.O.K.E./59
 43.99+8[2];1+8[
                        48: for J=1 to
                                                meter"; sto 73
 3] : 8 * 16 . 05 + 8 [4]
                         301
                                               71: if I=8:1bl
 16: S*30+S[5];S*
                        49: if I=3;1.67e
                                                "H.R.R. (kW/sa
  27.03+8[6];1+8[
                         2*.01*(C[3]-
                                                meter)";sto 73
  7];1+8[8]
                         R[3,J])/.02323+
                                               72: 1b1 C$[I],"
 17: dim T[301]
                         R[3,J]; eto 57
                                                (g/min-sa meter
 18: trk 1
                        50: if I=8;(R[8,
                                                1 "
 19: if B[3]=2.5;
                         J]+T[J]-C[11])*
                                               73: csiz 1.5,2,
 ldf 0:T[*]
                         C[10] *1000+R[8,
                                                8/11,90
 20: if B[3]=5;
                         J];9to 57
                                               74: for L=1 to
  ldf 1,T[*]
                        51: if I=7;R[7,
                                                10
 21: if B[3]=7.5;
                         J]→X
                                               75: plt -10,.1A*
 ldf 2,T[*]
                        52: -1000.23(X-
                                                L-.035*A,1
 22: ent "Channel
                         .5)(X-.425)(X-
                                               76: 161 A*.1*L
  to be plotted"
                         .2675)(X-.1225)
                                               77: next L
  • I
                         →Z[4]
                                               78: plt 600,A,-1
 23: dsp C$[I],
                        53: -46.616(X-
                                               79: gto 22
  "Flot"
                          .5)(X-.425)(X-
                                               80: end
                          .2675) +Z[3]
                                               *29193
```

FIGURE 2. CHI PLOTTING PROGRAM RATES

```
25: dsp "Set up
0: fmt 1:f2.8:7/
                                 - Plotter, press
",fz2.0
                                 cont"
1: fxd 0
                                26: stp
2: dsp "CHI Flot
                                27: if I=1;250+A
ter control-
                                 28: if I=2;2000+
intearals
                                  Ĥ
3: wait 5800
                                 29: if I=3;250+A
4: din H[5].8[6]
                                30: if I=4;200→A
,8$[20],C[11],
                                31: if I=5;20+A
 C$[8,20],R[8,
                                32: if I=6;10+A
301]
                                33: if I=7;250→A
5: ent "Input
                                34: if I=8;250+A
tape track and
                                35: fxd 0
file #",A,B
                                36: scl -50,620,
6: trk A
                                 -.1A,1.05A
7: 1df B,A[*],
                                 37: axe 0,0,30,
 B[*],B$,C[*],
                                 . 1 A
 ($,R[*]
                                 38: plt 200,.97A
8: wrt 16.1 A[1]
                                 , 1
 , A[2]
                                 39: csiz 3,2
9: prt B#
                                 40: 1b1 B$,B[1]
10: spc
                                 41: cplt -15,-1
11: prt "Materia
                              42: csiz 2,2
1 #",8[1]
                                 43: 1b1 "Burn";
                                 8[2],","
12: prt "Burn",
 P[2]
                                 44: fxd 1
13: fxd 1
                                 45: 1bl B[3],"
14: prt "W/cmt2"
                                 W/cm†2"
 , B [3]
                                 46: fxd 0
15: dim 8[8],
                                 47: plt 0,0,-2
 Z[4];.001063+S;
                                 48: for J=1 to
 8*28+8[1];8*
                                 301
 43.99+8[2];1+8[
                                 49: if I=3;1.67e
 3]; 8 * 16.05 + 8[4]
                                  2*.01*(20.9-
16: S*30+S[5];S*
                                 R[3,J])/.02323+
 27.03+8[6];1+8[
                                 R[3,J]; eto 57
 7];1+8[8]
                                 50: if I=8; (R[8,
17: dim T[301]
                                 J]-C[11])*C[10]
18: trk 1
                                 *1000+R[8,J];
19: if B[3]=2.5;
                                 eto 57
ldf 0,T[*]
                                51: if I=7;R[7,
20: if B[3]=5;
                                 J]÷X
 ldf 1,T[*]
                                 52: -1000.23(X-
21: if B[3]=7.5;
                                 .5)(X-.425)(X-
ldf 2,T[*]
                                 .2675)(X-.1225)
22: ent "Channel
                                 +Z[4]
 to be plotted"
                                53: -46.616(X-
 , I
                                  .5)(X-.425)(X-
23: dsp ($[[];
                                  .2675) + Z[3]
 "Plot"
24: wait 5000
```

FIGURE 3. CHI PLOTTING PROGRAM INTEGRALS (Sheet 1 of 2)

```
73: 161 C#[I];"
54: 249.326(X-
.5)(X-.425)+Z[2
                                   (9/sq meter)"
                                   74: csiz 1.5,2,
7
55: -102.666(X-
                                   8/11,90
.5) + Z[1]
                                   75: for L=1 to
56: if I=7;771.1
                                   10
*log(100/(Z[1]+
                                  76: plt -10,.1A*
 2[2]+2[3]+2[4])
                                   L-.035*A,1
                                   77: 161 A*.1*L
) →R [7, J]
57: R[I,J]*S[I]/
                                   78: next L
 30+T+T
                                   79: csiz 2,2,8/
58: plt (J-1) *2;
                                    11 * 0
                                   80: plt 420,.6A,
T
59: next J
                                   1
60: csiz 1.5,2
                                   81: 1bl C$[I],"
                                    Yield/sq meter
61: for K=1 to
 10
62: plt 60*K-20,
                                   82: plt 420,.55A
 -.05A,1
                                   + 1
63: 1bl K*60
                                   83: csiz 1.5,2;
64: next K
                                   fxd 1
65: peniplt 240;
                                   84: if I=3;1b1
 -.1A, -2
                                   " " * T ; " Watt *
66: csiz 2,2
                                   min"; sto 88
67: 1bl "Time
(sec)"
                                   85: if I=7;1bl
                                   Tieto 88
 68: plt -30,.3A,
                                   86: if I=8;1bl
                                   ":T:" Watt*
                                   min";sto 88
 69: csiz 2,2,8/
                                   87: fxd 1:1b) "
 11,90
                                   ":T:" erams"
 70: if I=3;161
                                   88: 0+T
 C$[I]," Heat
                                  89: plt 600,A,-1
 Release(kW-min/
                                  90: ato 22
 sa meter"; gto
                                  91: end
 74
 71: if I=7;161
                                  #7641
 "Total S.M.O.K.
 E./sq meter";
 9to 74
 72: if I=8;161
  "H.R.R. (KW-
 min/sq meter)";
```

eto 74

FIGURE 3. CHI PLOTTING PROGRAM INTEGRALS (Sheet 2 of 2)